FINAL PROGRESS REPORT

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INSTITUTION: Stanford University

GRANT TITLE: The Construction of a Compact, Inexpensive, Far Infrared FEL

REPORTING PERIOD: 1 April 1992 - 31 March 1995 (Final Report)

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OBJECTIVE: To develop a free electron laser (FEL) for the far infrared that will be modest in cost and size, and therefore be suitable for placement in an individual laboratory or hospital. The oscillator would operate in the range from 80 to 500μm, with megawatts of peak power and a 10μs macropulse.

APPROACH: The accelerator is compact and simple, consisting of a 1.5 cavity RF gun using a thermionic emitter and an accelerator length of 8cm. In this manner, beam energies in excess of 4MeV can be obtained which, for a wiggler period of 1cm, correspond to wavelengths shorter than 80 microns.

The wiggler consists of a staggered array of iron pole pieces in the field of a solenoid. Advantages of this design are that a strong wiggler field can be obtained with a short wiggler period; subsecond tuning over a 20-30% range is possible by varying the solenoid current; larger tolerances are possible than in a permanent magnet wiggler design; and a longitudinal magnetic field is present which helps to confine the beam.

The optical cavity uses a 2mm planar waveguide to confine the radiation in one transverse dimension, and two copper mirrors provide focusing in the orthogonal dimension. An on-axis hole is placed in the upstream mirror to permit both electron beam entry into the optical cavity without the need of a bending magnet, and optical radiation extraction.

ACCOMPLISHMENTS: The Far IR FEL (FIRFEL) lased at a wavelength of 86 μm. We observed four orders of magnitude increase in power over the coherent spontaneous emission. The net gain was measured to be 21% compared with a theoretical gain of 25%.

The spectrum was measured with a Fabry-Perot interferometer. We found the spectral width to be $\Delta\lambda/\lambda$ = 6.3% with an electron beam energy spread of $\Delta\gamma/\gamma$ = 3%. This is consistent with the expected spectral width to be 2 $\Delta\gamma/\gamma$ from

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Subj: RETURNED GRANTEE/CONTRACTOR TECHNICAL REPORTS

1. This confirms our conversations of 27 Feb 97 and 11 Jul 97. Enclosed are a number of technical reports which were returned to our agency for lack of clear distribution availability statement. This confirms that all reports are unclassified and are "APPROVED FOR PUBLIC RELEASE" with no restrictions.

2. Please contact me if you require additional information. My e-mail is *silverr@onr.navy.mil* and my phone is (206) 625-3196.

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the FEL synchronism condition. As the energy spread is reduced the spectral width should approach the transform limit of 2%.

We have demonstrated the usefulness of the 1.5 cell RF gun as the sole accelerator for FIRFEL. The gun provides 5 A of peak current in a 1% energy spread and a sufficiently low emittance ($\varepsilon_n = 10\ \pi$ mm-mrad) for operation in the far IR.

The staggered array wiggler was demonstrated for the first time. The wiggler yielded a 11.4 kG peak field with a 1 cm period, 1 mm gap and a 7 kG solenoid driving field. The field had only a 1.2% rms variation with no prior selection of pole pieces.

The optical cavity demonstrated for the first time the ability of an on-axis hole in the upstream mirror to be used simultaneously for electron injection into the wiggler and radiation extraction from the optical cavity.

We measured the current transmission through the wiggler and determined that nearly 100% of the current entering the wiggler travels through the 2 mm gap of the wiggler the entire length of the uniform magnetic field region. With the optical planar waveguide formed by the wiggler, the FEL has two synchronous wavelengths. For the parameters of our system these wavelengths are 2.7 mm and 80-300 μm. We have seen spontaneous emission from both of these synchronous wavelengths. The emitted optical power was seen to vary as the square of the current and to exhibit constructive and destructive interference as the downstream mirror is translated longitudinally. This is a demonstration of coherent spontaneous emission initiated by the harmonic content of the electron beam.

SIGNIFICANCE: We have designed a far infrared FEL device at a component cost under $300k. The FIRFEL is only several m^2 in size and the operation is simple enough to require only one operator. This transforms the FEL from the scale of a national facility or user center to the possibility of placing the FEL in an individual's laboratory or a hospital. The FEL's usefulness has been greatly enhanced by bringing the FEL to the user instead of vice versa.

PUBLICATIONS AND ABSTRACTS (last 3 years):

1. Y.C. Huang, H.C. Wang, R.H. Pantell, J. Feinstein, and J. Harris, "Performance characterization of a far-infrared, staggered wiggler," *Nucl. Instr. and Meth.*, A341, pp.431-5, 1994.

2. Y.C. Huang, H.C. Wang, R.H. Pantell, J. Feinstein, and J.W. Lewellen, "A staggered-array wiggler for far infrared, free-electron laser operation," *IEEE J. Quant. Elect.*, vol. 30, no. 5, pp. 1289-94, 1994.

3. Y.C. Huang, H. Wang, R.H. Pantell, J. Harris, J.F. Schmerge and J.W. Lewellen, "Electron beam characterization for a subcompact, far-infrared free-electron laser," to be published in *IEEE J. Quant. Elect.*, September, 1995.

4. J.W. Lewellen, J.F. Schmerge, J. Feinstein, R.H. Pantell and Y.C. Huang, "Preliminary emission characteristic measurements for a $300k FIR FEL," *Nucl. Instr. and Meth.*, A358, pp. 24-6, 1995.

5. Y.C. Huang, R.H. Pantell, J.F. Schmerge and J. Feinstein, "Maximization of FEL gain for a hole-coupled resonator," *Nucl. Instr. and Meth.*, A358, pp. 315-8, 1995.

6. J.F. Schmerge, J.W. Lewellen, Y.C. Huang, J. Feinstein and R.H. Pantell, "The free-electron laser as a laboratory instrument," *IEEE J. Quant. Elect.*, vol. 31, no. 6, pp. 1166-71, 1995.

7. J.W. Lewellen, J.F. Schmerge, R.H. Pantell and J. Feinstein, "A subcompact free-electron laser," to be published in *Proc. of the SPIE - the Inter. Soc. for Opt. Eng.*, Electron-Beam Sources of High-Brightness Radiation, vol. 2522B, 1995.